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A CORRELATION ANALYSIS OF HAWAII AND FOREIGN FISHERY STATISTICS FOR BILLFISHES, MAHIMAHI, WAHOO, AND PELAGIC SHARKS, 1962-78

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ABSTRACT

Investigated was the relationship between pelagic resources in the Pacific and their abundance within the Hawaii fishery, the effect of foreign longline fishing on the Hawaii pelagic fishery, and the consistency of abundance estimates derived from segments of the Hawaii pelagic fishery. We found that the domestic longline and troll statistics provided useable estimates of abundance of the more important commercial and recreational pelagic management unit species while deep-sea handline did not; that the domestic and foreign fisheries operated on common stocks of blue marlin, *Makaira mazara*, and striped marlin, *Tetrapturus audax*; that the abundance of blue and striped marlins available to the Hawaii fishery varied similarly to the stocks as measured in large central Pacific areas; that increased Japanese effort in these areas was associated with decreased stock abundance of blue and striped marlins available to the local fishery; and that this association was stronger in areas closer to Hawaii.

CONTENTS

INTRODUCTION

The relationship between the abundance of large, non-tuna pelagic resources in central Pacific study areas and their abundance within the Hawaii fishery was investigated. Similarly, the relationship between the amount and location of foreign longline fishing effort and the abundance of pelagic resources available to the Hawaii fishery was investigated. Lastly, whether statistics from the domestic longline, troll, and deep-sea handline fisheries produced consistent estimates of resource abundance was determined. This study was conducted in 1984 in support of efforts to develop a fishery management plan (FMP) for large, non-tuna pelagic fishes in the U.S. central and western Pacific under the Magnuson Fishery Conservation and Management Act. While the results of the study were provided informally at the time to fishery managers, this paper documents the findings because interest has continued and expanded to other management areas.

Correlation analysis was used to determine the extent of the fishery relationships characterized above. No attempt was made to model the relationships using predictive regression or simulation analysis. Assessing the two main objectives, the effects of stock variation and fishing pressure, was limited to the Indo-Pacific blue marlin, *Makaira mazara*, and striped marlin, *Tetrapturus audax*, because management interest focused on these species. Determining the consistency of abundance estimates involved these two species as well as the remainder of the species included in the FMP being developed, namely black marlin, *M. indica*; shortbill spearfish, *T. angustirostris*; sailfish, *Istiophorus platypterus*; swordfish, *Xiphias gladius*; mahimahi, *Coryphaena hippurus*; wahoo, *Acanthocybium solandri*; and sharks. Tuna were not included in the analysis because they were not covered by the Magnuson Act at that time.

A description of the background events leading up to this study and the fisheries involved will conclude this introduction. After the data and analytical methods are described, the results will be presented and discussed. Significant results will be given in the summary.

Background

In May 1978, the National Marine Fisheries Service (NMFS) approved the Preliminary Fishery Management Plan for Billfish, Oceanic Sharks, Wahoo, and Mahimahi for the Pacific Ocean, which was developed by the Southwest Region and the Honolulu Laboratory of the Southwest Fisheries Science Center. This was an interim measure until the regional fishery management councils could be established and could develop their own plans. Regulations did not go into effect until 1 April 1980, after which foreign longline fishing ceased in what is now called the U.S. Pacific Exclusive Economic Zone (EEZ). Later in 1978, the councils were formed, and they began developing FMPs. The Pacific Regional Fishery Management Council eventually dropped its effort to develop a billfish FMP, whereas the Western Pacific Regional Fishery Management Council (WPRFMC) persisted until the Fishery Management Plan for the Pelagic Fisheries of the Western Pacific Region was approved in July 1986. While political maneuvering dominated during the intervening years, a number of technical fishery issues were addressed as described below.

Regulations initially proposed in the draft Pelagic FMP included area and seasonal closures to foreign fishing. The WPRFMC's intention was to promote the development of the domestic fishery for pelagic species and to increase the domestic catch rate of management unit species while not managing foreign tuna fishing. Domestic fishermen and WPRFMC members perceived (and still do) that foreign tuna longline fishing in and adjacent to the EEZ adversely impacts domestic catches of management unit species and tunas. However, for the FMP to be approved, the proposed closures had to be shown to increase domestic catches and benefit the regional and national economies.

Several attempts were made to demonstrate the benefits of the proposed closures. First, Lovejoy (1977a, 1977b, 1981) constructed a simulation model of the stock dynamics of blue and striped marlins based on domestic and foreign fisheries data. On the basis of this model, he estimated that domestic catches of blue and striped marlins would increase 2% and 7%, respectively, if foreign longline fishing were prohibited in the EEZ. If all longline fishing were prohibited, the projected increases were 5% and 21%, respectively. Sensitivity studies of the model indicated that longline fishing would have a greater impact on troll catches at lower stock levels. The WPRFMC and the NMFS disagreed whether such increases were significant and detectable if the FMP were implemented. Also, repeated presentations on the utility of simulation modeling in general and the biological relationships derived from fisheries data and incorporated into the specific simulation model failed to allay the concerns of critics.

Second, Wetherall and Yong (1983) performed a regression analysis of blue marlin estimates of abundance in local, adjacent, and mid-Pacific areas by using Japanese tuna longline effort and catch statistics. They found that variation in blue marlin abundance at the beginning of the year in a mid-Pacific area explained 80% of the annual variation in third-quarter abundance within the local area around the main Hawaiian Islands. No other predictors of local resource abundance were found to be significant. The amount of variance accounted for by their regression model was increased to 95% by forcing variables for recruitment and effort within local, adjacent, and mid-Pacific areas into the model. However, the contributions of these additional terms were not statistically significant. Wetherall and Yong (1983) concluded that the abundance of blue marlin in

Hawaiian waters is largely determined by population trends in a broad mid-Pacific area. This result supported Lovejoy's (1977a) use of Japanese effort and catch data for estimating abundance of blue marlin and the use of a Pacific pooled area supplying fish to the Hawaii fishery. With so little variation in the data unaccounted for, by inference the local fishery could not have been having a large influence on blue marlin abundance.

Third, at a WPRFMC meeting in 1982, the Southwest Region indicated that the proposed FMP could be approved if domestic catches and catch rates of pelagic species had increased after April 1980 when foreign longlining ceased in the EEZ. Lovejoy (1981) recommended the same test during his second review of the billfish situation. In response, the WPRFMC collected purchase data on management unit species from six major wholesale fish dealers, because 1980-82 statistics were not then available from the Hawaii Division of Aquatic Resources. These purchase data, compared with earlier State landings data, showed conclusively that purchases (landings) of blue marlin and other pelagic species had increased. However, with only purchase data available from the dealers, it could not be shown whether domestic fishing effort had increased and thus caused the increased catches. In addition, the purchase data provided no information on whether blue marlin abundance also had increased. Hence, the NMFS concluded that the data did not support approval of the draft Pelagic FMP.

Fourth, in 1984 at the request of the WPRFMC, the NMFS agreed to expand the Wetherall and Yong (1983) study by conducting the study described in the present paper. The expansion included determining the relationship between variation in foreign fishing and local striped marlin abundance. Also, domestic effort and catch data were added for use in assessing the effects of foreign fishing and to estimate the abundance of pelagic resources available to the local fishery. These abundance estimates, calculated for each of the domestic fisheries, were examined for consistency.

The Fisheries

The domestic tuna longline fishery, as it was conducted around 1980, was a scaled-down version of that used by the Japanese distant-water tuna longline fishery. The main line was fiber rope divided into segments called baskets. Each basket was suspended from floats to which flag poles were attached; thus, "flagline" will be used to differentiate domestic from Japanese longline. From 4- to 13-hook droppers were attached to each basket of the main line. Domestic vessels fished 500-1,500 hooks while 2,000 or more hooks were deployed from the Japanese vessels. Longline gear was set and hauled in deep, pelagic waters on a daily basis.

Trolling in Hawaii is conducted from small runabouts to moderate-sized, diesel-powered commercial vessels. The deep-sea handline fishery for pelagic species is made up of two fisheries, both utilizing small runabouts. The night handline fishery, called *ika shibi*, is conducted by first catching squid attracted by lights. Then, the squid are used as bait on handlines to catch yellowfin tuna, *Thunnus albacares*, and bigeye tuna, *T. obesus*, and incidentally catch management unit species. The day handline fishery, called *palu ahi* after the ancient Hawaiian method, targets yellowfin tuna. It is conducted by lowering chum bags and baited hooks to the desired fishing depth.

DATA AND METHODS

The data examined in this study were from 1962 through 1978. Data for 1979 were not included because the quality of the domestic data was questionable. Statistics on the domestic fisheries were extracted from the Catch Report Data Base provided by the Division of Aquatic Resources of the Hawaii Department of Natural Resources. Technically, this data set contains the weight of fish by date of landing rather than actual catches by date of capture (logbook data). Since Korean and Taiwanese tuna longline operations were virtually nonexistent in the area during the study period, only Japanese data were used. The Japanese statistics were derived from the tuna longline logbook data base provided by the Japan Fisheries Agency, Research Division.

For the domestic data, landings were recorded in pounds and converted to the metric system, and a unit of fishing effort was defined as a catch record appearing in the data base. For troll and deep-sea handline, a unit of fishing effort was presumed to be a 1-day trip. In contrast, for flagline fishing, a unit of fishing effort was assumed to be a multiple-day trip. Since the date of departure for trips was not recorded in the data base, no adjustment for trip length was possible. In addition, flagline boats often off-load over a period of days, resulting in multiple catch records for a single trip. No attempt was made to correct for this problem; therefore, our estimates of fishing effort for flagline fishing differed from those used by Wetherall and Yong (1983). All catch records for flagline and troll fishing were used in the analysis because tuna and the management unit species are the primary targets of these fisheries. For deep-sea handline fishing, only those records with landings of the management unit species or tuna were used. Those records consisting of only bottomfish or reef fish (most of the records) were ignored. Effective effort was used for the pelagic management unit species or tuna because zero-catch trips, even if reported, were not included in the State's data set.

For the Japanese data, the fishery statistics consisted of fishing effort in number of hooks fished and the resulting catch in number of fish. Japanese statistics were compiled by geographical areas for comparison with domestic statistics (Fig. 1, Table 1). For blue marlin, the same local, adjacent, and mid-Pacific areas were used as in Wetherall and Yong (1983). For striped marlin, the same local, a larger adjacent (5° added to the northern boundary of the blue marlin adjacent area), and an eastern Pacific area (rather than the mid-Pacific area) were used. The adjacent areas did not include the local area, and the mid-Pacific area did not include the local area or the blue marlin adjacent area.

Catch, fishing effort, and calculated catch rate were compiled by month, quarter, and year for flagline, troll, deep-sea handline, and longline. The nominal fishing effort statistics were not standardized. Catch rate, as an estimate of relative abundance, was calculated as total catch divided by total effort for each of the periods and the four fisheries. Because the foreign and domestic effort and catch data differed considerably in magnitude, centered indices were also plotted to facilitate interpretation of trends. Centering consisted of subtracting the mean from the individual values.

The relationships of the fisheries with one another were evaluated with the Spearman correlation coefficient, a nonparametric statistic using ranks. This statistic was used because neither fishing effort nor abundance estimates generally are normally distributed. The significance of the correlation coefficients was tested using a table of the distribution of the correlation coefficient (Beyer 1966), which is comparable to using the Student's t distribution. Kendall's Tau B sign statistic, another nonparametric correlation coefficient, provided comparable results, despite being more sensitive to runs or serial correlation.

Before correlations were computed using the long-term monthly and quarterly effort, catch, and abundance estimates, the data were deseasonalized. However, it was not possible to deseasonalize monthly abundance estimates because too many values were missing. The X-11 Procedure, developed by the U.S. Census Bureau, was used to deseasonalize the data (SAS Institute, Inc. 1988). Rather than using the complete procedure which removes seasonal as well as incidental effects, the procedure was stopped after taking a weighted 13-month or 5-quarter moving average. Thus, only the seasonal effect was removed. In addition, the complete procedure did not handle well the small magnitudes common with estimates of relative abundance and resulted in substantial manipulation of the observed values. Hence, we concluded that the complete procedure was not appropriate for these data.

Using correlation analysis to determine the relationship between resource-wide and local variation in relative stock abundance was straightforward in that estimates of abundance from separate fleets were used. However, determining the relationship between the foreign fishing in or near the Hawaiian Islands and the success of the domestic fishery may be subject to secondary correlations. The most obvious way of testing for the latter effect would be to use foreign effort and domestic catch. However, catch depends on the amount of fishing effort expended, and foreign and domestic effort levels are influenced by the tuna market which has international linkages. Thus, also tested was the more rigorous hypothesis of whether a negative relationship exists between foreign fishing and the abundance of the resources available for domestic harvest. Also, to help avoid secondary correlations, the correlation between foreign and domestic effort was tested. Plots of annual and seasonal effort and abundance estimates for foreign and domestic fisheries were used to visualize data trends and interpret tested results.

RESULTS

Fishing Effort

Domestic

The number of annual flagline trips was somewhat greater than for the handline and troll fisheries at the start of the time series but was lower by the end (Fig. 2A). Annual flagline fishing effort was generally above its long-term mean through 1970 and below it in later years (Fig. 2B). Annual troll effort increased markedly starting in 1969, so by 1973, it was above the long-term mean. Annual handline effort followed a similar trend, with values after 1970 being above the long-term mean. Both troll and handline effort declined abruptly in the last year. Seasonally, troll fishing effort showed a strong single mode in summer; handline effort generally increased through much of the year, with the highest value occurring in October; and flagline effort oscillated, with highs in June and December (Fig. 2C).

Foreign

The annual number of Japanese tuna longline hooks fished in the local and blue marlin-adjacent areas showed no trend over the study period (Fig. 3A-B). In the mid-Pacific area, the trend in fishing effort apparently was cyclical, with highs in 1963 and 1972 and lows in 1968 and 1978. Seasonally, fishing effort was highest during May in the local and blue marlin-adjacent areas and during February-March in the mid-Pacific area (Fig. 3C).

Long-Term Correlations

For the domestic fishery, annual, quarterly, and monthly flagline effort was negatively correlated with troll and handline effort (Table 2). Annual, quarterly, and monthly troll effort was positively correlated with handline fishing effort. For the longline fishery, monthly effort levels in the local area were positively correlated with that in the blue and striped marlin-adjacent areas. Also, annual, quarterly, and monthly effort levels in the local area were negatively correlated with those in the mid-Pacific area. Monthly and quarterly effort levels in both adjacent areas were positively correlated with those in the mid-Pacific area.

Comparing the domestic and Japanese fisheries, quarterly and monthly flagline effort levels were negatively correlated with longline effort in the local area. However, only monthly flagline effort was negatively correlated with longline effort in the striped marlin-adjacent area. In contrast, quarterly and monthly flagline effort levels were positively correlated with foreign effort in the mid-Pacific area. Troll and handline effort levels were positively correlated with longline effort in the local and both adjacent areas, but negatively correlated in the mid-Pacific area.

Seasonal Correlations

Long-term average monthly fishing effort levels for the domestic fisheries were not significantly correlated (Table 3). Likewise, long-term average longline fishing effort in the four areas and long-term average domestic effort were not significantly correlated, except in one case. Longline effort in the mid-Pacific area and handline effort were negatively correlated. For average monthly fishing effort, positive relationships generally were found between the local and adjacent areas and between the adjacent and mid-Pacific areas.

Estimates of Relative Abundance

Annual Domestic

Estimates of relative abundance of blue marlin derived from flagline and troll statistics were similar, but handline estimates were much lower (Fig. 4A). Estimates of blue marlin abundance from flagline statistics declined to below the long-term average in 1971-72 and then began increasing, nearly reaching the long-term average by 1978 (Fig. 4B). Abundance estimates for the troll fleet followed a similar pattern but were more variable. For handline, no significant trend in abundance was evident. Black marlin abundance was low in the three domestic fisheries (Fig. 5A) and more variable in the first half of the time series (Fig. 5B). Black marlin abundance estimates from troll and handline fishing rose above the long-term mean in the mid-1970s. Striped marlin abundance in the flagline fishery was much higher than for troll and handline, particularly early in the time series (Fig. 6A). In the flagline fishery, striped marlin abundance increased during 1962-68 and declined sharply thereafter, falling below the long-term average in 1971 (Fig. 6B). Striped marlin abundance in the troll and handline fisheries varied little from their means but, in contrast to flagline, tended to be above their respective long-term means after 1970.

In the troll and handline fisheries, abundance of sailfish (Fig. 7), shortbill spearfish (Fig. 8), and swordfish (Fig. 9) showed little variation from their respective long-term means. For the flagline fishery, sailfish abundance rose sharply above the long-term average during 1964-67 and then declined slowly through 1978, falling below the long-term mean after 1969. Shortbill spearfish abundance was below the long-term mean until 1969, after which it customarily fluctuated above the mean. Swordfish abundance for the flagline fishery declined in 1962-72, fell below the long-term mean in 1970, held steady for several years, and increased abruptly to 1960 levels or above in 1977-78. Mahimahi abundance exhibited a cyclical pattern (Fig. 10), with higher values in 1962-66 and 1970-73. This was particularly true for the flagline and handline fisheries. Wahoo abundance in the flagline, troll, and handline fisheries fluctuated, with little evidence of a trend (Fig. 11). For sharks, which historically have had little market value, no trend was evident.

Seasonal Domestic

The 17-year average monthly estimates of relative abundance of blue marlin in the flagline and troll fisheries showed strong seasonal trends, with highs during summer and fall (Fig. 12). In the handline fishery, blue marlin abundance was comparatively much lower, with the highest values occurring in January and July. Black marlin abundance was relatively low and showed no consistency among the three fisheries. Striped marlin abundance in the flagline fishery showed a marked seasonal trend, with highs throughout winter and spring. Comparatively, striped marlin abundance in the troll and handline fisheries was smaller, with highs generally occurring during the summer and fall. Relative abundance estimates of sailfish and shortbill spearfish in the flagline fishery were higher during the first half of the year. Troll and handline estimates for sailfish were comparatively low and showed no trend. Shortbill spearfish estimates for these fisheries also were low, but estimates for the troll fishery were higher during the first 6 months. Swordfish abundance in the handline fishery and particularly the flagline fishery showed increased values in spring to early summer; abundance estimates in the troll fishery were extremely low and showed no obvious trend. Mahimahi abundance showed a strong bimodal seasonal pattern, with modes in April and October-November for all three fisheries. Wahoo abundance was highest in summer, with the broadness of the mode varying among the three fisheries. Abundance estimates for sharks were highly variable both within and between the fisheries.

Annual Foreign

For the Japanese longline fishery, since the estimates of annual relative abundance for the geographical areas were the same order of magnitude, only centered estimates by species are presented (Fig. 13). Blue marlin abundance showed a consistent downward trend in the local, adjacent, and mid-Pacific areas. Black marlin abundance during the 6 years before 1968 (except 1963) were greater than the long-term average in the local and adjacent areas; this was true for only 2 of the 11 subsequent years. Striped marlin abundance was variable but generally increased from 1962 through 1968, then declined markedly in 1969 and gradually thereafter. Combined sailfish and shortbill spearfish abundance increased from 1962 to 1966 or 1967, depending on the area, and then declined gradually. Swordfish abundance in the local and adjacent areas was high in the first year or two of the series, depending on the area, then gradually increased through 1978 from a low in 1964.

Seasonal Foreign

Seventeen-year average monthly abundance estimates for the Japanese longline fishery in the local and adjacent areas are in Figure 14. Blue marlin abundance showed a single peak in summer in both areas, earlier than for the domestic flagline fishery. Black marlin abundance (not plotted) showed little seasonal trend. Striped marlin abundance was bimodal with peaks occurring in April-May and October-November in both areas. The spring peak was higher in the local area. Longline striped marlin seasonality corresponds reasonably well with that for flagline, except the latter showed less of a decline in December, January, and February. Combined sailfish and shortbill spearfish abundance showed little seasonality. Swordfish were most abundant in April and lowest in February and March, while a minor peak occurred in November in the local area. In the adjacent area, the seasonality was unimodal with the high appearing in March. The observed trend in the local area was similar to that for flagline, although the summer mode for the latter was more pronounced.

Correlations Between Estimates of Relative Abundance

Seasonal Domestic

The correlations between 17-year average monthly estimates of relative abundance for blue marlin, striped marlin, mahimahi, and wahoo for the domestic fisheries are in Table 4. Blue marlin abundance estimates for the flagline and troll fisheries were positively correlated. Monthly abundance estimates of striped marlin for the flagline fishery were negatively correlated with those computed for the troll and handline fisheries, whereas those for the troll and handline fisheries were positively correlated. Mahimahi seasonal abundance estimates for the handline and troll fisheries, as well as those for the handline and flagline fisheries were positively correlated. However, seasonal estimates of abundance for the flagline and troll fisheries were not correlated. For wahoo, seasonal abundance estimates for all domestic fisheries were positively correlated.

Long-Term Domestic and Foreign

The correlations of abundance estimates over the 17-year period, calculated using annual and deseasonalized quarterly statistics for the domestic fisheries and Japanese longline, are in Tables 5, 6, and 7. These are double-correlation tables in that the half-table correlations for two separate species are included in each table to save space.

Among the domestic fisheries, the annual and quarterly abundance estimates of blue marlin for the flagline and troll fisheries were positively correlated (Table 5, upper right). Blue marlin abundance for handline was not correlated with flagline or troll abundance estimates. For the Japanese fishery, annual and quarterly blue marlin abundance estimates were positively correlated between the local, adjacent, and mid-Pacific areas. Generally, flagline and troll blue marlin abundance estimates were positively correlated with longline abundance estimates in all three areas, while handline abundance estimates were generally not. Among the domestic fisheries, long-term estimates of quarterly striped marlin stock abundance were positively correlated only between the troll and handline fisheries (Table 5, lower left). Quarterly abundance estimates for flagline were negatively correlated with troll and handline abundance estimates. For the Japanese fishery, striped marlin abundance estimates between the local and adjacent areas were positively correlated. Abundance estimates for striped marlin in the eastern Pacific area were not correlated with those in any other area (or with those for the domestic fishery); hence, they were not included in the table. When comparing estimates of striped marlin abundance derived for domestic and Japanese statistics, flagline and longline estimates for local and adjacent areas were positively correlated. Quarterly abundance estimates for the troll fishery were negatively correlated with those for the longline fishery in the local area, whereas quarterly handline abundance estimates were negatively correlated with those for the longline fishery in the adjacent area.

For swordfish abundance estimates, the only significant correlation among the domestic fisheries was between the flagline and handline fisheries, and the relationship was positive (Table 6, upper right). Longline abundance estimates for the local and adjacent areas were positively correlated. When comparing estimates of abundance derived for the domestic and Japanese fisheries, only troll and longline estimates in the local and adjacent areas were correlated, and the relationships were positive. Among the domestic fisheries, black marlin quarterly long-term estimates of abundance were positively correlated between the troll and handline fisheries (Table 6, lower left). Annual and quarterly flagline and handline abundance estimates were also correlated. For the longline fishery, abundance estimates in the local and adjacent areas were positively correlated. Domestic abundance estimates were positively correlated in most cases with those for the longline fishery in the local and adjacent areas.

Among the domestic fisheries, combined sailfish and shortbill spearfish annual and quarterly estimates of relative abundance were positively correlated only between the handline and troll fisheries (Table 7). Quarterly handline and flagline estimates of relative abundance estimates were positively correlated. Flagline and troll estimates were not correlated. For the longline fishery, abundance estimates in the local and adjacent areas were positively correlated. Comparing the domestic and foreign fisheries, annual and quarterly flagline abundance estimates were positively correlated with those for the longline fishery in the local area. In the adjacent area, only quarterly data showed a significant, positive correlation. Then, quarterly troll and handline abundance estimates were negatively correlated with those of the longline fishery in the adjacent area. For mahimahi, wahoo, and sharks, correlations were only possible for the domestic fishery (Table 8). For mahimahi, only handline and flagline abundance estimates were positively correlated. For wahoo, flagline and troll estimates were positively correlated. For sharks, quarterly abundance estimates for the flagline fishery were correlated with those for the troll and handline fisheries.

Correlations Between Estimates of Relative Abundance with Lags

The correlations between deseasonalized quarterly estimates of blue marlin abundance for longline and the three domestic fisheries, lagged by different periods are in Table 9. The flagline and troll abundance estimates were positively correlated with those for the longline fishery in all areas with lags of 1-4 quarters. Handline estimates with lags of 3-4 quarters were negatively correlated with those in the longline fishery in only the local area. The correlations between striped marlin abundance estimates for the longline fishery and the three domestic fisheries lagged by different periods are presented in Table 10. Flagline estimates were positively correlated with those for longline in both local and adjacent areas with lags of 1-4 quarters. Troll estimates for lags of 1-2 quarters were negatively correlated with those for the longline fishery in the local area. Handline abundance estimates with a 4-quarter lag were negatively correlated with those for the longline fishery in the local area and with lags of 1-4 quarters in the adjacent area. No tests involving the eastern Pacific were significant (not reported in Table 10).

Correlations Between Long-term Abundance and Fishing Effort

Estimates of long-term quarterly abundance of blue marlin in the flagline fishery were negatively correlated with longline effort in local and adjacent areas (Table 11). No other associations for blue marlin were significant. Striped marlin quarterly abundance estimates in the flagline fishery and longline fishing effort were negatively correlated in the local and adjacent areas. Striped marlin abundance estimates in the troll fishery were positively correlated with longline effort in the local area. No significant correlations were found with longline effort in the eastern Pacific area (not reported in Table 11).

Correlations Between Abundance with Lags and Fishing Effort

The correlations between long-term, longline fishing effort and lagged blue and striped marlin long-term abundance for the domestic fishery are in Table 12. For blue marlin, the relationship between longline effort and abundance in the domestic fisheries was not consistent. Flagline abundance estimates with a 1-quarter lag were negatively correlated with longline fishing effort in the local area only. For the troll fishery, there were no significant correlations. Handline blue marlin abundance estimates with lags of 1-4 quarters were positively correlated with longline effort in the local area. For striped marlin, abundance estimates in the flagline fishery with lags of 1-4 quarters were negatively correlated with longline effort in the adjacent area. Abundance estimates in the troll fishery with lags of 1-4 quarters were positively correlated with longline effort in the local area and with a 4-quarter lag in the adjacent area. For the handline fishery, there were no significant relationships. Again, no significant correlations were found with longline effort in the eastern Pacific area (not reported in Table 12).

Correlations Between Long-term Catches and Fishing Effort

The correlations between blue and striped marlin long-term catches by the domestic fisheries and long-term longline fishing effort are in Table 13. For blue marlin, flagline catches were negatively correlated with longline effort in the local area. Troll catches were positively correlated with longline fishing effort in the local area and negatively correlated in the mid-Pacific area. Handline catches showed no significant relationships. For striped marlin, quarterly flagline catches were negatively correlated with longline fishing effort in the local area. Annual and quarterly troll catches were positively correlated in the local area. Handline catches were positively correlated in the local area. Again, no significant correlations were found with longline effort in the eastern Pacific area (not reported in Table 13).

Correlations Between Catches with Lags and Fishing Effort

Long-term blue marlin catches by the flagline fishery with a 1-quarter lag were negatively correlated with longline fishing effort in the local area only (Table 13). Troll catches with lags of 1-4 quarters were positively correlated with longline effort in the local area and negatively correlated in the mid-Pacific area. Handline catches with lags of 3-4 quarters were negatively correlated with longline effort in the mid-Pacific area. For striped marlin, flagline catches with lags of 1-4-quarters were negatively correlated with longline fishing effort in the local area; those with lags of 1-4 quarters were negatively correlated in the adjacent area. Troll catches of striped marlin with lags of 1-4 quarters were positively correlated with longline effort in the local area. Handline catches with lags of 1-4 quarters were positively correlated with longline effort in the local area. Again, no significant correlations were found with longline effort in the eastern Pacific area (not reported in Table 13).

DISCUSSION

The findings in this study were not as consistent or statistically strong (low variance accounted for even though statistically significant) as one would like. Several factors contributed to this: routine fishery data were used rather than data collected using a sampling program designed to address the questions posed; inadequate knowledge of the biology and stock structure of the less abundant marlins as well as mahimahi, wahoo, and shark; lack of data on mahimahi and wahoo in the Japanese statistics; sailfish and shortbill spearfish statistics being combined in the Japanese data and shark statistics being combined in the domestic and Japanese data; the poor quality of domestic statistics except those for dominant, commercially important species; and the small size of the domestic fishery.

Fishing Effort

Since CPUE is used to estimate relative abundance, correlated fishing effort between fisheries can affect the correlations computed for their abundance estimates. Likewise, since the amount of fishing effort determines catch, dependencies between fishing effort statistics in different fisheries can also affect the correlations computed between fishing effort in one fishery and the catches in another. Thus, variation in fishing effort is discussed at some length.

Our analyses show that increases in the amount of handline and troll fishing and coincidental decreases in longline fishing occurred over several years. The expansion of the troll and day and night handline fisheries in Hawaii in the 1980s probably was in response to economic conditions. These conditions included high tuna prices, which tracked inflation; the large, expanding market for fresh tunas in Hawaii and the U.S. mainland; and the low capital required to enter the fisheries. The development of new handline fishing grounds also may have contributed. In contrast, the decline in the flagline fishery for tunas is believed to have been due to aging of the boats and lack of replacement capital investment, but no study has been conducted to investigate this. During 1990, this trend reversed with a dramatic increase in boats participating in the fishery. There is no evidence that the reciprocal changes in these fisheries were the result of changes in resource availability or biological fishery competition between the fisheries. That is, there is no evidence that increased fishing effort by the surface fisheries caused a decline in flagline fishing, nor that a decline in flagline fishing allowed expansion of the surface fisheries.

Japanese fishing effort showed no indication of a long-term change in local and adjacent waters but showed a definite decline in the larger mid-Pacific area. However, this view is biased because the size of the areas are quite different. For example, the number of hooks per square kilometer in the local and adjacent areas actually increased, albeit variably. In the mid-Pacific area, the trend was downward, resulting in the number of hooks per square kilometer becoming about the same in all three areas by 1978.

While the flagline fishery decreased, Japanese fishing effort increased in the local and adjacent areas at the expense of effort in the mid-Pacific area. Also, the domestic troll and handline fisheries were expanding. Although the correlations between these fisheries were statistically significant, these results do not in themselves imply cause and effect. These relationships should be considered, however, when interpreting subsequent analyses of catch and abundance estimates.

Monthly and quarterly fishing effort for the three domestic fisheries followed dissimilar trends, indicating that the fishermen had different seasonal fishing strategies. Also, while quarterly statistics may be easier and cheaper to analyze, monthly statistics more adequately describe seasonal variation. The variation in Japanese fishing effort indicates that similar seasonal strategies were used in the local and adjacent areas but that a different strategy was followed in the mid-Pacific area. No relationship was apparent between seasonal domestic and Japanese effort statistics in the different areas. However, out of 9 comparisons, one significant correlation (between handline and longline effort in the mid-Pacific area) was found, whereas only 1 out of 20 would be expected by random chance alone at $P = 0.05$.

Estimates of Relative Abundance

Because relative stock abundance was estimated using CPUE, correlations between the abundance estimates of these three fisheries can be affected by correlations between their effort (and catch) statistics. While blue marlin estimates of abundance for the flagline and troll fisheries and the longline fishery for all areas declined from 1962 through 1974 or 1975 and then increased, fishing effort followed two different trends. Flagline and mid-Pacific longline effort declined while troll effort and longline effort in local and adjacent areas increased. In addition, the estimates of abundance were always positively correlated while only half of the between-fisheries effort comparisons were positively correlated. Thus, we concluded that CPUE provide a useable measure of abundance and the correlation results were meaningful. The seasonal variation in estimates of abundance for these fisheries indicated heightened abundance during the summer. Thus, on the basis of these results, we inferred that the flagline, troll, and longline fisheries provided satisfactory estimates of relative abundance of blue marlin. Also, because the estimates of relative abundance for these fisheries were positively correlated, we concluded that the fisheries operated on a common stock. In contrast, blue marlin abundance estimates for the handline fishery were low and not correlated with the other estimates. Therefore, we decided that statistics from the handline fishery did not provide useable estimates of blue marlin abundance.

For striped marlin, while flagline and local and adjacent longline estimates of abundance were positively correlated, their effort statistics were negatively correlated. Seasonally, these fisheries showed heightened abundance in spring and fall and low abundance in the summer and winter. Thus, we concluded that statistics from these fisheries provided valid abundance estimates and that the fisheries operated on a common stock. The lack of correlation with abundance estimates for the eastern Pacific area was surprising because generally it is believed that striped marlin move from the eastern to the western Pacific as they age and approach maturity. A few fish tagged in the eastern

Pacific have been recaptured in the central Pacific (J. L. Squire, Jr., La Jolla Laboratory, Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA 92038-0271, pers. commun.). Since abundance estimates for troll and handline fisheries were negatively correlated with those for flagline and longline fisheries and did not vary substantially, they either provided estimates of abundance of some other stock segment or, more likely, did not provide reliable abundance estimates. We judged the latter to be the case for the following reasons. First, striped marlin constitute a minor, incidental component of the surface fishery. Second, since the troll and handline fisheries had been expanding and their effort statistics were correlated, not unexpectedly their abundance estimates also were correlated. Third, the seasonal variation in abundance differed significantly from both the flagline and longline fisheries.

For black marlin, the abundance estimates for the domestic fisheries showed large variability between years and a weak indication of a downward trend. For the Japanese data, a downward trend was more apparent. Seasonally, the estimates for troll and handline fishing varied similarly but not the same as for the flagline fishery. Finally, longline data from the local and adjacent areas showed no indication of seasonality. Based on these results, plus the knowledge that black marlin are associated more with coastal, continental waters than with insular environments, none of these fisheries, foreign or domestic, provided useable estimates of relative abundance for this species. While some significant correlations between the estimates of combined sailfish and shortbill spearfish abundance for the three domestic fisheries were found, the results were inconsistent. This was also true for correlations between these and estimates from the longline fishery in the local and adjacent areas. Thus, our confidence in the estimates from the domestic fisheries was weak. Because the estimates from the longline fishery in the local and adjacent areas were consistent, more confidence can be placed in them. With sailfish being more abundant along the eastern and western Pacific coastal margins and shortbill spearfish in central Pacific waters, the combined abundance estimates for longline in the areas used in this study were probably more indicative of shortbill spearfish than sailfish. This was certainly true of the Hawaii abundance estimates.

For swordfish, the annual and seasonal estimates of relative abundance for the domestic and foreign fisheries generally were inconsistent, with the only significant positive relationship between the longline and troll fisheries. However, longline estimates between areas were consistent. Given these results, none of the domestic fisheries provided reliable estimates of abundance while the foreign longline estimates did. For mahimahi, estimates of annual abundance from all three domestic fisheries declined similarly, and seasonal variation was consistently bimodal. Based on these consistent patterns, statistics from the three domestic fisheries provided reliable estimates of abundance, and long-term abundance had declined. Data were not available for the Japanese longline fishery (or the pole-and-line fishery) to compare with the domestic statistics.

For wahoo, estimates of annual abundance from the flagline and troll fisheries increased while estimates from handlining declined for much of the period. Increases later in the series may have been related to increased tourism and enlarged restaurant demand. Seasonal abundance estimates for all three domestic fisheries showed similar patterns. Thus, we concluded that all three domestic fisheries provided valid estimates of relative abundance. Foreign data were not available for comparison. For sharks, both the domestic and foreign data were composites of several species. Since market demand for sharks is very low in Hawaii, boat operators seldom land them and are not motivated to record their capture. The unusually high abundance value in 1977 for the flagline fishery was probably due to a shark consumption promotion by the University of Hawaii Sea Grant Program. None of these fisheries provided reliable estimates of shark abundance.

Relationships Between Lagged Abundance Estimates

The relationships between the lagged abundance estimates were computed to determine stock structure and temporal changes in resource abundance or movement. Unfortunately, these comparisons could be done only with blue and striped marlins which were the only species having, in our estimation, reliable estimates of abundance for both the domestic and foreign fisheries.

Variations in blue marlin abundance within the domestic fishery (flagline and troll) and in the longline fishery in the local, adjacent, and mid-Pacific areas were similar even when the domestic data were lagged 1-4 quarters. Comparable results were found for striped marlin between the domestic fishery (flagline) and the Japanese fishery in the local and adjacent areas. Based on these results, the domestic and the foreign longline fishery in the central Pacific exploited the same stocks of blue and striped marlins. In other words, changes observed in local abundance of these species were comparable to changes in the abundance of the stocks occurring over a wide area in the central Pacific. Since the EEZ comprises only a small part of the stock ranges of these species, changes in their abundance within the EEZ were determined largely by events occurring in foreign or international waters. Wetherall and Yong (1983) reached the same conclusion for blue marlin. The significant lag effects indicate there was autocorrelation in the estimates of abundance or, in less technical terms, there was a great deal of consistency in the abundance estimates over time for each of the fisheries.

Relationships Between Local Abundance and Foreign Effort

Since fishing effort is assumed to be proportional to the mortality caused by fishing gear, correlating abundance estimates derived from domestic gear with longline fishing effort tests whether foreign-induced mortality in local, adjacent, and mid-Pacific waters was associated with reduced local abundance estimated using domestic fishery statistics. It is tempting to regard this as a test of cause and effect, but such an interpretation does not necessarily follow from using correlation analysis to explore relationships in data not collected with an experimental design.

The estimates of blue marlin abundance calculated from flagline fishery data were negatively correlated with Japanese fishing effort expended in the local and adjacent areas during the same quarter and in the local area 1 quarter previously. None of the tests for the mid-Pacific area was significant. Since the effort statistics involved in these comparisons were negatively and significantly correlated, the negative signs of the effort-abundance relationships were unexpected and heightened our confidence in the results. That is, if two effort statistics are correlated, then catch divided by one of the effort statistics (as an estimate of abundance) would be expected to be positively correlated with the other effort statistic on purely arithmetic grounds. The correlation values for the troll fishery, with and without lags, were also negative in the local area, but none was statistically significant. Thus, we concluded that increases in foreign fishing effort in waters close to the domestic fishery were associated with decreases in the abundance of blue marlin available to the domestic fisheries (and vice versa). This was not surprising given the results of Lovejoy (1977a, 1977b, 1981). In fact, our results, which are statistically significant, provide confirmation of his modeling results which could not be statistically tested. Our results do not, however, address the magnitude of his predictions.

The estimates of striped marlin abundance calculated from flagline data were also negatively correlated with longline fishing effort expended in local and adjacent areas during the same quarter and in the adjacent area 1-4 quarters earlier. Since the effort statistics were also correlated negatively, this result was unexpected, and our confidence in the result was heightened. But since the troll data did not provide quality estimates of striped marlin abundance, their correlation with effort could not be used to evaluate the validity of the relationship. Thus, we concluded, with slightly less confidence than with blue marlin, that increases in Japanese fishing effort in both the local and adjacent areas around Hawaii were associated with decreases in the abundance of striped marlin available to the domestic fishery (and vice versa). Interestingly, the correlation coefficients for the lagged effects in the adjacent area were more significant ($P \leq 0.01$) than during the same quarter ($P \leq 0.05$).

Relationships Between Domestic Catch and Foreign Effort

While determining the relationships between foreign fishing effort and the abundance of resources available to the domestic fisheries is biologically interesting, members of the fishing industry and the WPRFMC are interested in whether foreign fishing affects domestic catch. There are, however, problems in interpreting the correlation results from such tests. Our results indicated that decreased domestic catches of blue and striped marlins, particularly in the flagline fishery, were associated with increased Japanese fishing effort in areas close to Hawaii. In addition, the greater the distance from Hawaii, generally the weaker and less certain the relationships became. As an extreme example, troll catches of blue marlin were negatively correlated with longline effort in the mid-Pacific area but were positively correlated in the local area.

Since domestic catch results from domestic fishing (effort), the relationships between domestic and foreign effort must be examined to interpret the relationship between catch and foreign effort. Whenever domestic catches and foreign effort levels were negatively correlated, domestic and foreign effort were negatively correlated. Also, in the one instance when domestic catches and foreign effort levels were positively correlated, domestic and foreign effort also were positively correlated. Therefore, we concluded that these routine fishery statistics could not be used to test for an effect of foreign fishing on domestic catches. Increased foreign effort near Hawaii was, we surmised, related to decreased *abundance* of blue and striped marlins available to the domestic fishery, but not necessarily to the success of the Hawaii pelagic fishery at harvesting these resources.

SUMMARY

This investigation extended the earlier study of the relationship between the domestic flagline fishery for blue marlin and the Japanese tuna longline fishery by Wetherall and Yong (1983) to include striped marlin. Also, abundance estimates computed for the flagline, troll, and deep-sea handline fisheries for blue, black, and striped marlins, sailfish, shortbill spearfish, swordfish, mahimahi, wahoo, and shark were compared for consistency. The fishing effort statistics for these three domestic fisheries and the longline fishery indicated that they had different seasonal fishing strategies. The Japanese fleet followed a similar seasonal fishing strategy in the local, adjacent, and mid-Pacific areas. The annual effort statistics for the troll and handline fisheries were positively correlated with Japanese effort in the local and adjacent areas, but negatively correlated with longline effort in the mid-Pacific area and with flagline effort.

For blue marlin, flagline, troll, and longline statistics provided good estimates of abundance, and abundance declined until 1975 when an increase became apparent. These abundance estimates were positively correlated, and we concluded that the domestic and foreign fleets fished a common stock. For striped marlin, flagline and longline statistics provided good estimates of abundance, and abundance declined after an initial period of stability. These estimates of abundance also were positively correlated, and we inferred that the domestic and foreign fisheries operated on a common stock. For black marlin and sharks, none of the fisheries provided reliable estimates of abundance. For swordfish and combined sailfish and shortbill spearfish, only longline statistics provided reliable estimates of abundance. For mahimahi, the domestic fisheries all provided good measures of stock abundance, and abundance declined. For wahoo, the flagline and troll fisheries provide usable estimates of abundance, and abundance was variable, possibly increasing slightly.

The relationships between domestic measures of abundance for blue marlin for flagline and troll gear and striped marlin for flagline gear were all positive. Likewise, the relationships of these domestic measures with comparable measures for the longline fishery in the same time frame and in earlier quarters were positive. This result indicates that changes occurring in stock abundance in waters outside of the domestic fishery are reflected in the domestic fishery in the same period and later. That is, events occurring outside of the waters of the local fishery determined the abundance of blue and striped marlins available to the local fishery.

Increases in foreign longline effort were associated with decreased abundance of blue and striped marlins available to the local flagline and troll fisheries. The strength of the relationship decreased with distance from Hawaii. Similar results were found to be true for fishing effort in previous quarters. Thus, higher levels of foreign fishing effort during the same and previous periods were associated with lower abundance of blue and striped marlins available to the local fishery.

While there were statistically significant relationships between domestic catches and foreign effort, the signs of the relationships were what would be expected based on the signs of the correlations between the effort statistics. Thus, we concluded that the comparisons of domestic catches and foreign effort provided no useful management information.

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Table 1.--Geographical areas used for longline statistics.

	Latitude and longitude	
	Blue marlin	Striped marlin
Area		
Local	15°-25°N, 155°-160°W	15°-25°N, 155°-160°W
Adjacent	10°-25°N, 150°-165°W	10°-30°N, 150°-165°W
Mid-Pacific	10°-25°N, 150°-150°E	
Eastern Pacific		20°-35°N, 105°-130°W

Table 2.--Spearman correlation coefficients, using annual (N = 17), deseasonalized quarterly (N = 68), and deseasonalized monthly (N = 203) nominal fishing effort, between the three domestic fisheries and the foreign longline fishery (in local, adjacent, and mid-Pacific areas).

	Domestic fishery		Area of longline fishery			
	Troll	Handline	Local	Striped marlin-adjacent	Blue marlin-adjacent	Mid-Pacific
Domestic fishery						
Flagline						
Annually	-0.767**	-0.679**	-0.448	-0.208	-0.103	0.306
Quarterly	-0.682***	-0.670**	-0.416**	-0.176	-0.097	0.258*
Monthly	-0.678**	-0.617**	-0.334**	-0.159*	-0.097	0.259**
Troll						
Annually		0.880**	0.561*	0.235	0.034	-0.539*
Quarterly		0.906**	0.471**	0.270*	0.116	-0.449**
Monthly		0.907**	0.447**	0.248**	0.104	-0.437**
Handline						
Annually			0.397	0.275	0.091	-0.208
Quarterly			0.405**	0.419**	0.300*	-0.170
Monthly			0.379**	0.390**	0.269**	-0.159*
Area of longline fishery						
Local						
Annually				0.174	0.154	-0.537*
Quarterly				0.169	0.134	-0.420**
Monthly				0.198**	0.170*	-0.397**
Striped marlin-adjacent						
Annually						0.059
Quarterly						0.260*
Monthly						0.262**
Blue marlin-adjacent						
Annually						0.061
Quarterly						0.293*
Montlhly						0.280**

*$P \leq 0.05$.
*$P \leq 0.01$.

Table 3.--Spearman correlation coefficients (N = 12), using 17-year average monthly nominal fishing effort, between the three domestic fisheries and the foreign longline fishery (in local, adjacent, and mid-Pacific areas).

	Domestic fishery		Area of longline fishery			
	Troll	Handline	Local	Striped marlin-adjacent	Blue marlin-adjacent	Mid-Pacific
Domestic fishery						
Flagline	0.028	0.294	0.552	0.434	0.427	-0.112
Troll		0.301	0.252	0.126	0.366	-0.224
Handline			-0.119	-0.392	-0.371	-0.706*
Area of longline fishery						
Local				0.790**	0.790**	0.377
Striped marlin-adjacent						0.741**
Blue marlin-adjacent						0.601*

*$P \leq 0.05$.
**$P \leq 0.01$.

Table 4.--Spearman correlation coefficients (N = 12), using 17-year average monthly abundance estimates of blue marlin, striped marlin, mahimahi, and wahoo, between the three domestic fisheries.

	Blue marlin		Striped marlin		Mahimahi		Wahoo	
	Troll	Handline	Troll	Handline	Troll	Handline	Troll	Handline
Flag-line	0.650*	0.476	-0.881**	-0.615*	0.524	0.769**	0.916**	0.853**
Troll		0.524		0.587*		0.867**		0.783**

*$P \leq 0.05$.
**$P \leq 0.01$.

Table 5.--Spearman correlation coefficients, using annual (N = 17) and seasonally adjusted quarterly (N = 68) long-term abundance estimates of blue marlin and striped marlin, between the three domestic fisheries and the foreign longline fishery (in local, adjacent, and mid-Pacific areas).

	Domestic fishery			Area of longline fishery		
	Flagline	Troll	Handline	Local	Adjacent	Mid-Pacific
Domestic fishery						
Flagline				**Blue marlin**		
Annually		0.564*	0.100	0.860**	0.750**	0.735**
Quarterly		0.632**	0.206	0.749**	0.740**	0.744**
Troll						
Annually	-0.451		0.199	0.549*	0.417	0.532*
Quarterly	-0.438**		0.233	0.588**	0.580**	0.620**
Handline						
Annually	-0.326	0.478		-0.105	-0.292	-0.441
Quarterly	-0.398**	0.490**		-0.135	-0.268	-0.241
Area of longline fishery						
Local						
Annually	0.926**	-0.370	-0.311		0.924**	0.882**
Quarterly	0.860**	-0.384**	-0.148		0.940**	0.912**
Adjacent						
Annually	0.917**	-0.260	-0.348	0.914**		0.922**
Quarterly	0.902**	-0.255	-0.303*	0.894**		0.955**
		Striped marlin				

*$P \leq 0.05$.
**$P \leq 0.01$.

Table 6.--Spearman correlation coefficients, using annual (N = 17) and seasonally adjusted quarterly (N = 68) long-term abundance estimates of swordfish and black marlin, between the three domestic fisheries and the foreign longline fishery (in local, adjacent, and mid-Pacific areas).

	Domestic fishery			Area of longline fishery	
	Flagline	Troll	Handline	Local	Adjacent
Domestic fishery					
Flagline			Swordfish		
Annually		-0.168	0.492	0.140	0.140
Quarterly		-0.225	0.624	-0.184	0.205
Troll					
Annually	0.171		0.385	0.363	0.309
Quarterly	-0.007		0.174	0.664**	0.431**
Handline					
Annually	0.694**	0.414		0.416	0.171
Quarterly	0.573**	0.415**		-0.033	0.232
Area of longline fishery					
Local					
Annually	0.640**	0.511*	0.775**		0.507*
Quarterly	0.613**	0.262*	0.550**		0.360*
Adjacent					
Annually	0.735**	0.352	0.513*	0.502*	
Quarterly	0.575**	0.295*	0.387**	0.495**	
		Black marlin			

*$P \leq 0.05$.
**$P \leq 0.01$.

Table 7.--Spearman correlation coefficients, using annual (*N* = 17) and seasonally adjusted quarterly (*N* = 68) long-term abundance estimates of sailfish and shortbill spearfish combined, between the three domestic fisheries and the foreign longline fishery (in local, adjacent, and mid-Pacific areas).

	Domestic fishery		Area of longline fishery	
	Troll	Handline	Local	Adjacent
Domestic fishery				
Flagline	**Sailfish-Shortbill spearfish**			
Annually	0.289	0.424	0.748**	0.434
Quarterly	0.194	0.324**	0.710**	0.356**
Troll				
Annually		0.494*	-0.047	-0.233
Quarterly		0.500**	-0.084	-0.367**
Handline				
Annually			0.020	-0.367
Quarterly			0.016	-0.313
Area of longline fishery				
Local				
Annually				0.728**
Quarterly				0.615**

* $P \leq 0.05$.
** $P \leq 0.01$.

Table 8.--Spearman correlation coefficients, using annual (*N* = 17) and seasonally adjusted quarterly (*N* = 68) long-term abundance of mahimahi, wahoo, and sharks, between the three domestic fisheries.

	Mahimahi		Wahoo		Sharks	
	Troll	Handline	Troll	Handline	Troll	Handline
Flagline						
Annually	0.196	0.610**	0.618**	0.074	0.362	0.413
Quarterly	0.070	0.717**	0.591*	0.057	0.271	0.412**
Troll						
Annually		-0.076		-0.150		0.148
Quarterly		-0.245		-0.032		0.230

*$P \leq 0.05$.
**$P \leq 0.01$.

Table 9.--Spearman correlation coefficients, using seasonally adjusted quarterly (N = 68) long-term abundance of blue marlin with lags of 1-4 quarters, between the three domestic fisheries and the foreign longline fishery (in local, adjacent, and mid-Pacific areas).

		Area of longline fishery		
		Local	Adjacent	Mid-Pacific
Domestic flagline				
Quarter lag	1	0.723**	0.738**	0.752**
	2	0.684**	0.722**	0.748**
	3	0.634**	0.690**	0.727**
	4	0.585**	0.648**	0.691**
Domestic troll				
Quarter lag	1	0.613**	0.620**	0.685**
	2	0.610**	0.622**	0.720**
	3	0.574**	0.581**	0.710**
	4	0.514**	0.522**	0.655**
Domestic handline				
Quarter lag	1	-0.172	-0.246	-0.213
	2	-0.229	-0.231	-0.193
	3	-0.307	-0.245	-0.179
	4	-0.387	-0.276	-0.190

*$P \leq 0.05$.
**$P \leq 0.01$.

Table 10.--Spearman correlation coefficients, using quarterly (*N* = 68) long-term abundance of striped marlin, between the three domestic fisheries with lags of 1-4 quarters and the foreign longline fishery (in local and adjacent areas).

	Area of longline fishery	
	Local	Adjacent
Domestic flagline		
Quarter lag 1	0.858**	0.877**
2	0.841**	0.824**
3	0.823**	0.757**
4	0.808**	0.690**
Domestic troll		
Quarter lag 1	-0.330**	-0.208
2	-0.276*	-0.195
3	-0.231	-0.210
4	-0.214	-0.244
Domestic handline		
Quarter lag 1	-0.172	-0.323**
2	-0.204	-0.337**
3	-0.246	-0.347**
4	-0.303*	-0.347**

*$P \leq 0.05$.
**$P \leq 0.01$.

Table 11.--Spearman correlation coefficients between long-term abundance of blue and striped marlins for the three domestic fisheries and long-term foreign longline fishing effort (in local, adjacent, and mid-Pacific areas) calculated annually (N = 17) and quarterly (N = 68; seasonally adjusted).

	Domestic abundance estimates					
	Striped marlin			Blue marlin		
	Flagline	Troll	Handline	Flagline	Troll	Handline
Area of longline fishery						
Local						
Annually	-0.336	0.223	0.270	-0.397	0.074	0.299
Quarterly	-0.286*	0.304*	0.228	-0.315*	-0.121	0.108
Adjacent						
Annually	-0.321	0.039	0.098	-0.179	0.179	-0.167
Quarterly	-0.278*	-0.005	0.002	-0.264*	0.008	-0.146
Mid-Pacific						
Annually				0.350	0.015	-0.194
Quarterly				0.221	0.083	-0.086

*$P \leq 0.05$.

Table 12.--Spearman correlation coefficients, using seasonally adjusted quarterly (N = 68) long-term abundance of blue and striped marlins, with lags of 1-4 quarters, between the domestic fisheries and foreign longline fishing effort (in local, adjacent, and mid-Pacific areas).

	Area of longline fishery		
	Local	Adjacent	Mid-Pacific
Blue marlin abundance			
Flagline			
Quarter lag 1	-0.253*	-0.211	0.195
2	-0.197	-0.159	0.168
3	-0.171	-0.126	0.158
4	-0.164	-0.114	0.177
Troll			
Quarter lag 1	-0.056	0.049	0.145
2	-0.031	0.071	0.191
3	-0.058	0.055	0.175
4	-0.144	0.018	0.100
Handline			
Quarter lag 1	0.217	-0.139	-0.044
2	0.333**	-0.122	-0.057
3	0.440**	-0.062	-0.121
4	0.461**	0.016	-0.172
Striped marlin abundance			
Flagline			
Quarter lag 1	-0.205	-0.398**	
2	-0.149	-0.374**	
3	-0.156	-0.348**	
4	-0.205	-0.312*	
Troll			
Quarter lag 1	0.342**	0.085	
2	0.346**	0.160	
3	0.328**	0.248	
4	0.290*	0.322*	
Handline			
Quarter lag 1	0.244	0.029	
2	0.246	0.027	
3	0.206	-0.013	
4	0.161	-0.025	

*$P \leq 0.05$.
**$P \leq 0.01$.

Table 13.--Spearman correlation coefficients between annual (N = 17) and seasonally adjusted quarterly (N = 68) long-term catches of blue and striped marlins for the three domestic fisheries and long-term foreign longline fishing effort (in local, adjacent, and mid-Pacific areas).

	Domestic catches					
	Striped marlin			Blue marlin		
	Flagline	Troll	Handline	Flagline	Troll	Handline
Area of longline fishery						
Local						
Annually	-0.294	0.525*	0.424	-0.424	0.696**	0.414
Quarterly	-0.255*	0.492**	0.334**	-0.363**	0.515**	0.283*
Adjacent						
Annually	-0.164	0.181	0.284	-0.186	0.169	-0.142
Quarterly	-0.205	0.097	0.168	-0.231	0.197	-0.027
Mid-Pacific						
Annually				0.350	-0.480	-0.294
Quarterly				0.250	-0.374**	-0.159

*$P \le 0.05$.
**$P \le 0.01$.

Table 14.--Spearman correlation coefficients between seasonally adjusted quarterly (N = 68) long-term catches of blue and striped marlins for the three domestic fisheries, with lags of 1-4 quarters, and foreign longline fishing effort (in local, adjacent, and mid-Pacific areas).

		Area of longline fishery		
		Local	Adjacent	Mid-Pacific
Domestic blue marlin catches				
Flagline	Quarter lag 1	-0.287*	-0.192	0.196
	2	-0.205	-0.149	0.146
	3	-0.149	-0.119	0.111
	4	-0.120	-0.128	0.095
Troll	Quarter lag 1	0.579**	0.193	-0.374**
	2	0.601**	0.171	-0.403**
	3	0.587**	0.151	-0.457**
	4	0.530**	0.127	-0.522**
Handline	Quarter lag 1	0.353**	-0.035	-0.178
	2	0.437**	-0.10	-0.228
	3	0.526**	0.053	-0.282*
	4	0.554**	0.114	-0.318*
Domestic striped marlin catches				
Flagline	Quarter lag 1	-0.192	-0.336**	
	2	-0.171	-0.326**	
	3	-0.203	-0.323*	
	4	-0.277*	-0.320*	
Troll	Quarter lag 1	0.497**	0.202	
	2	0.493**	0.202	
	3	0.495**	0.222	
	4	0.485**	0.262	
Handline	Quarter lag 1	0.316*	0.243	
	2	0.315*	0.197	
	3	0.314*	0.132	
	4	0.303*	0.102	

*$P \leq 0.05$.
**$P \leq 0.01$.

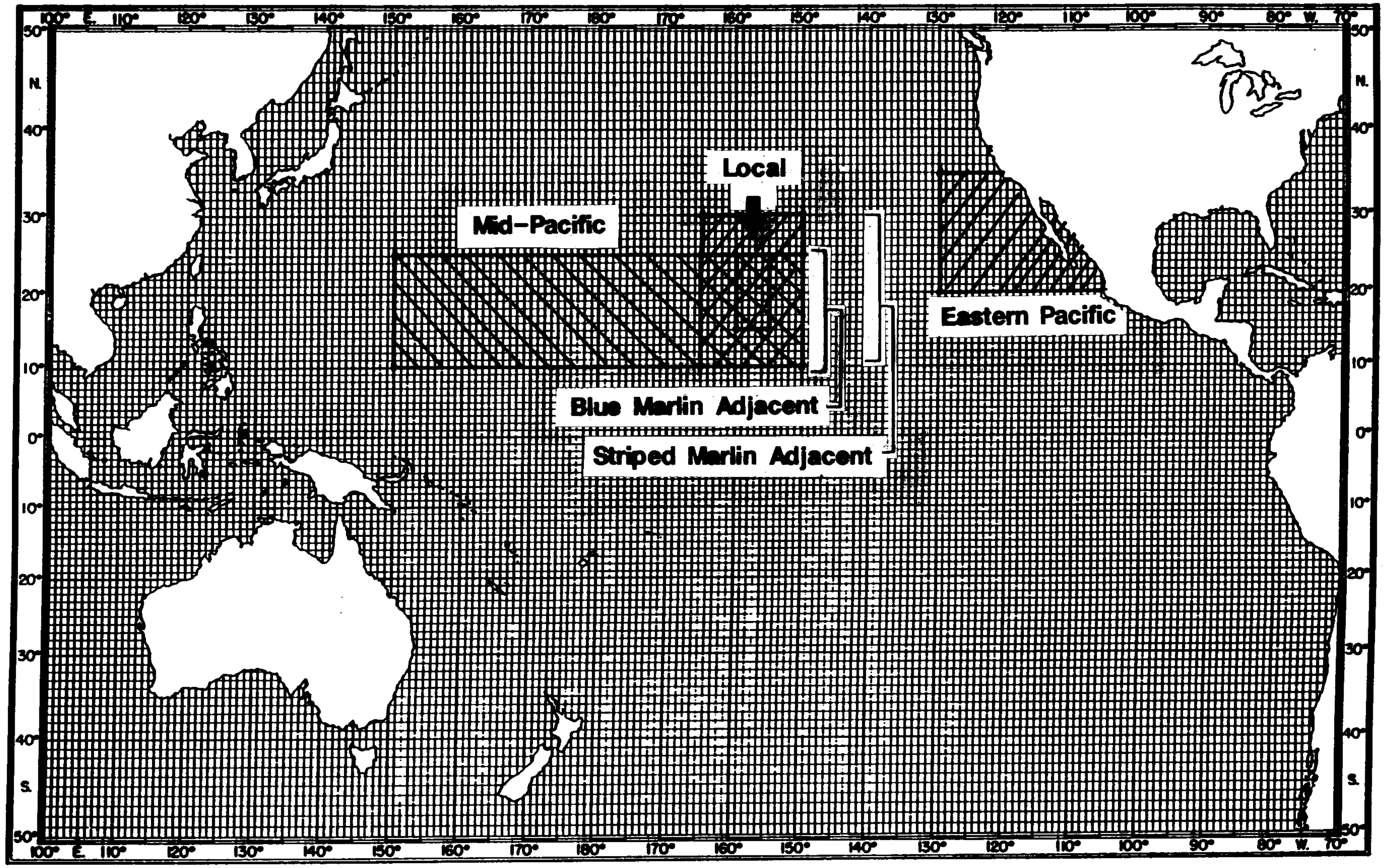


Figure 1.--Geographical areas used for Japanese longline statistics. Blue marlin areas ▧. Striped marlin areas ▨.

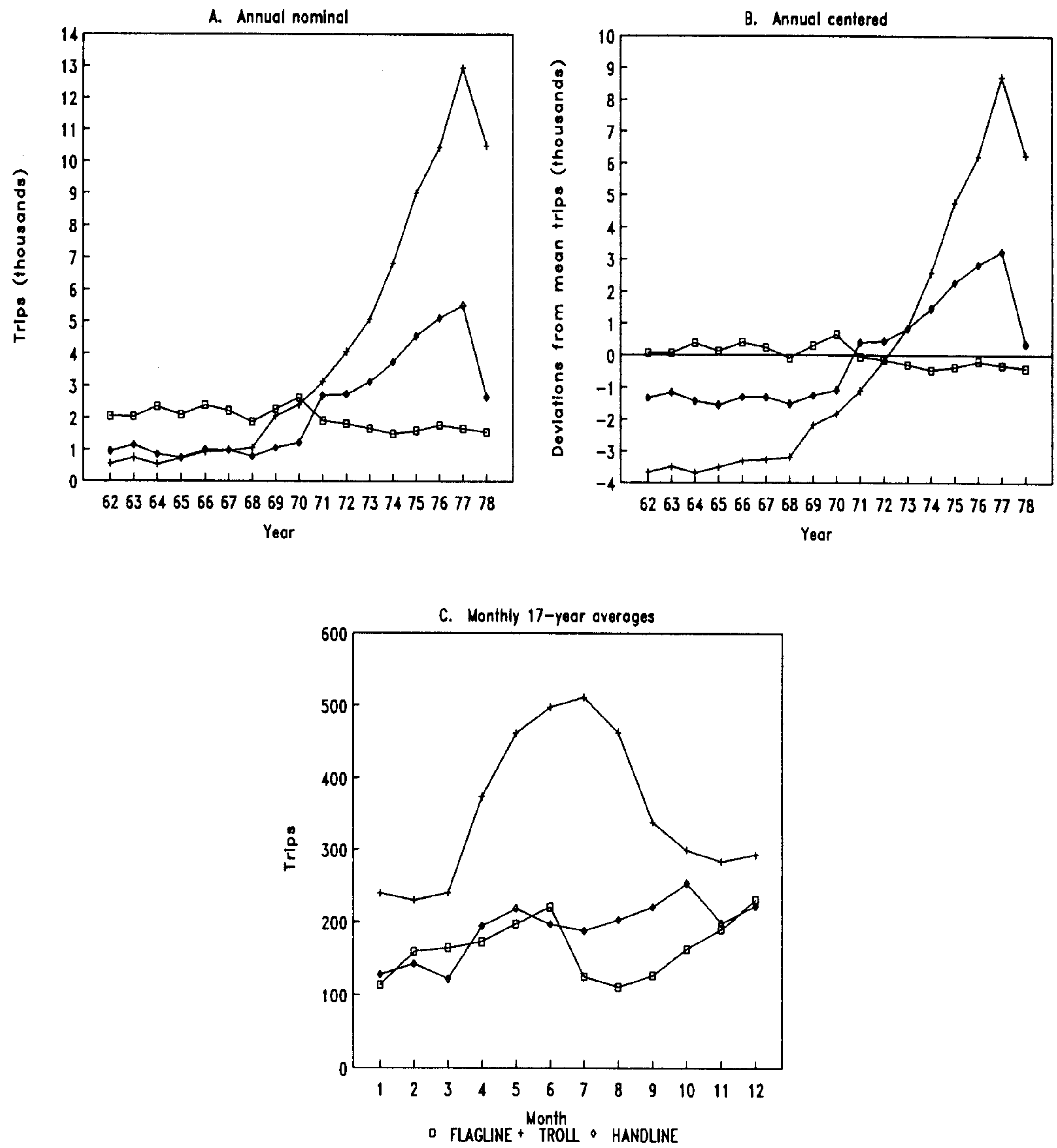


Figure 2.--Effective fishing effort (catch records or presumed trips) for Hawaii flagline, troll, and handline fishing.

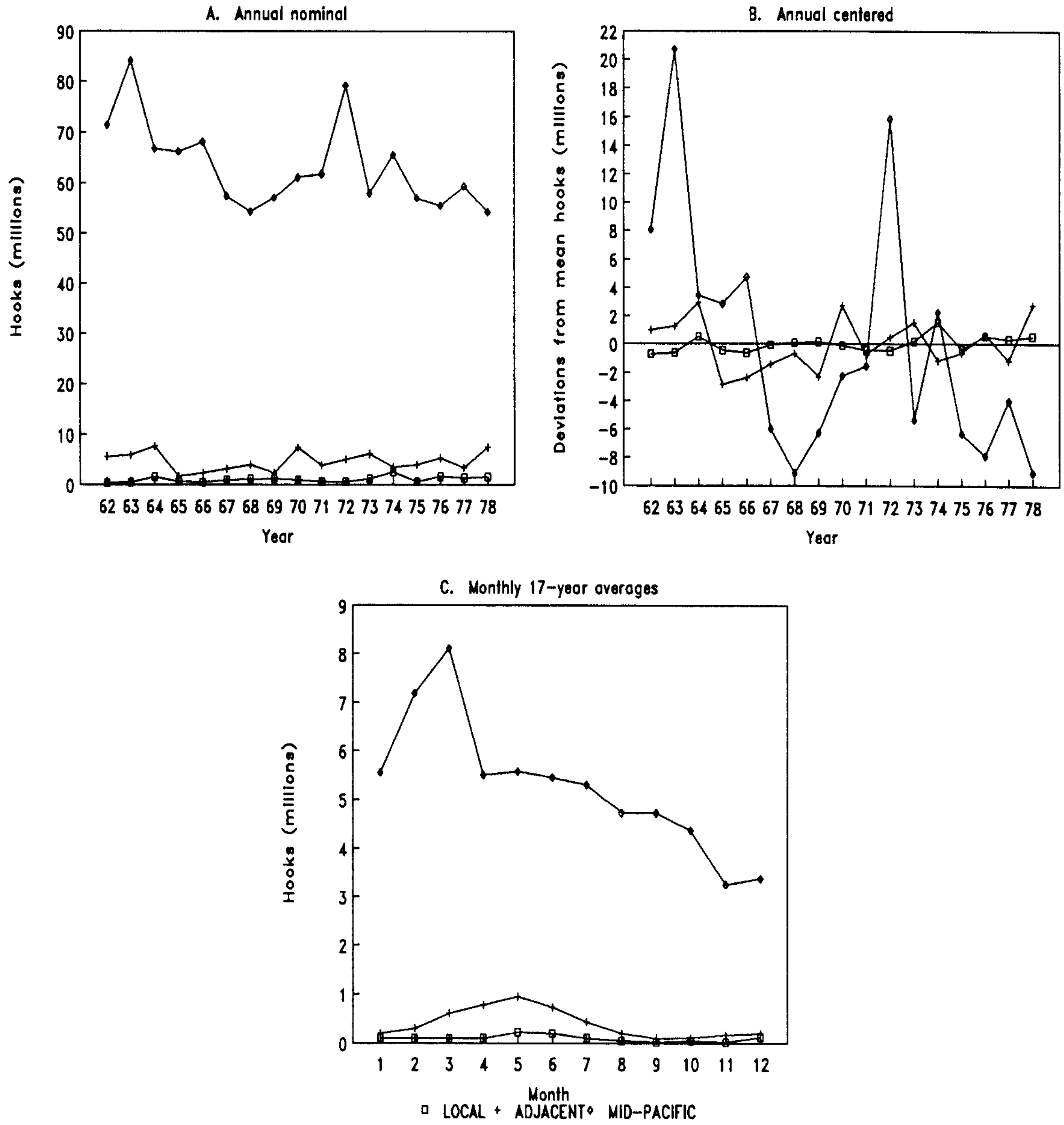


Figure 3.--Fishing effort for Japanese tuna longline in local, blue marlin-adjacent, and mid-Pacific areas.

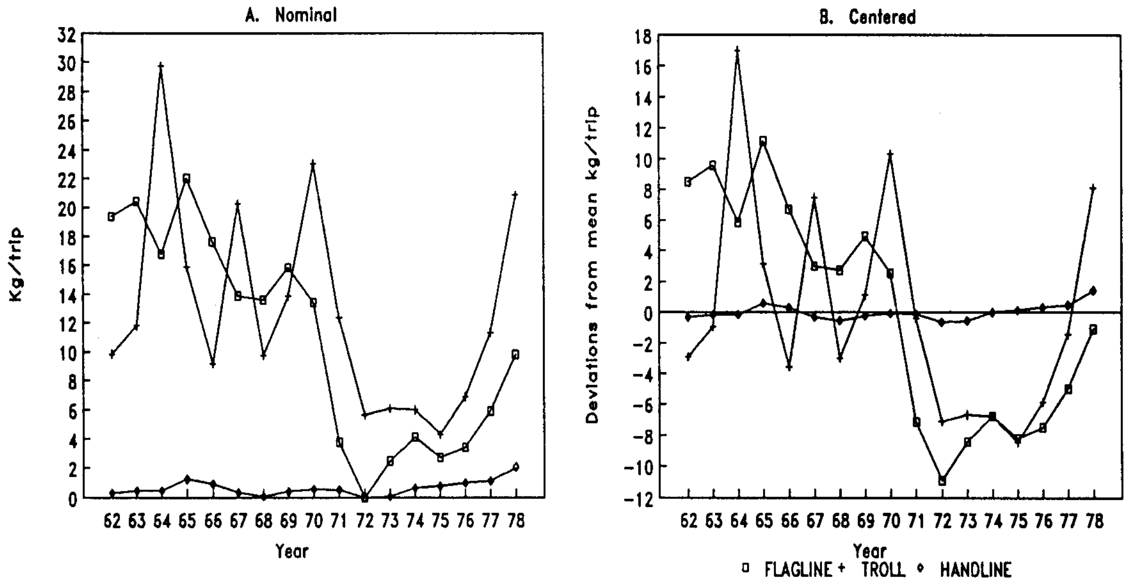


Figure 4.--Annual blue marlin catch rates (in kilogram per presumed trip) for domestic flagline, troll, and handline.

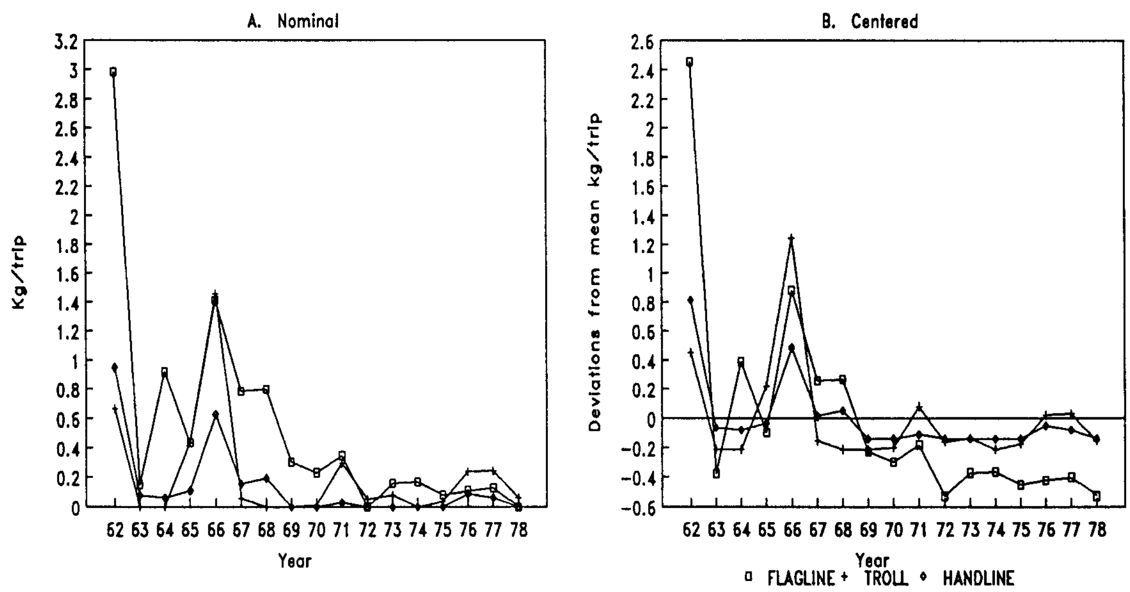


Figure 5.--Annual black marlin catch rates (in kilograms per presumed trip) for domestic flagline, troll, and handline.

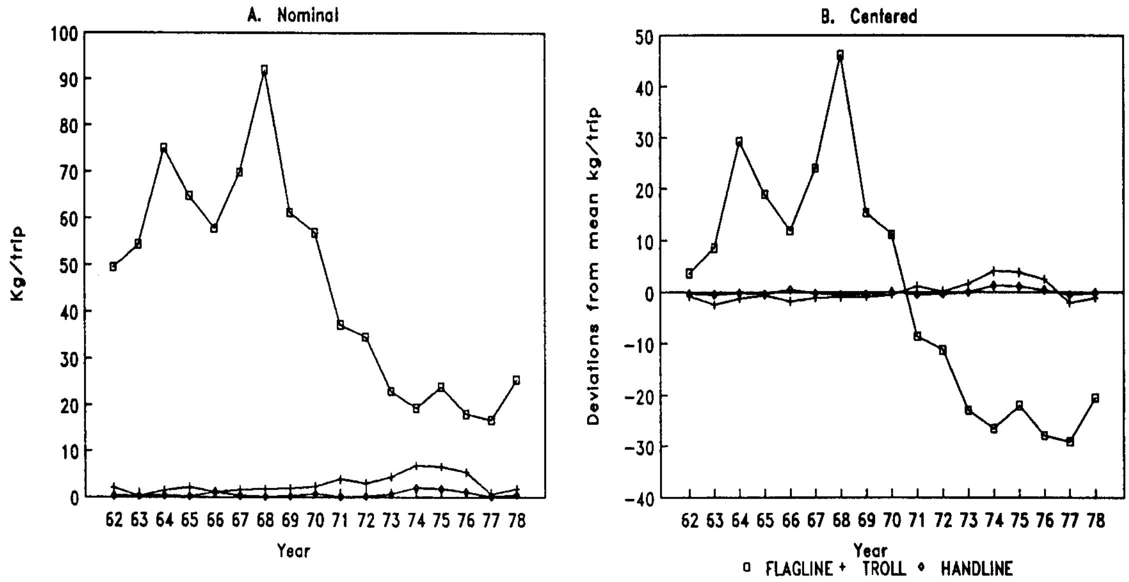


Figure 6.--Annual striped marlin catch rates (in kilogram per presumed trip) for domestic flagline, troll, and handline.

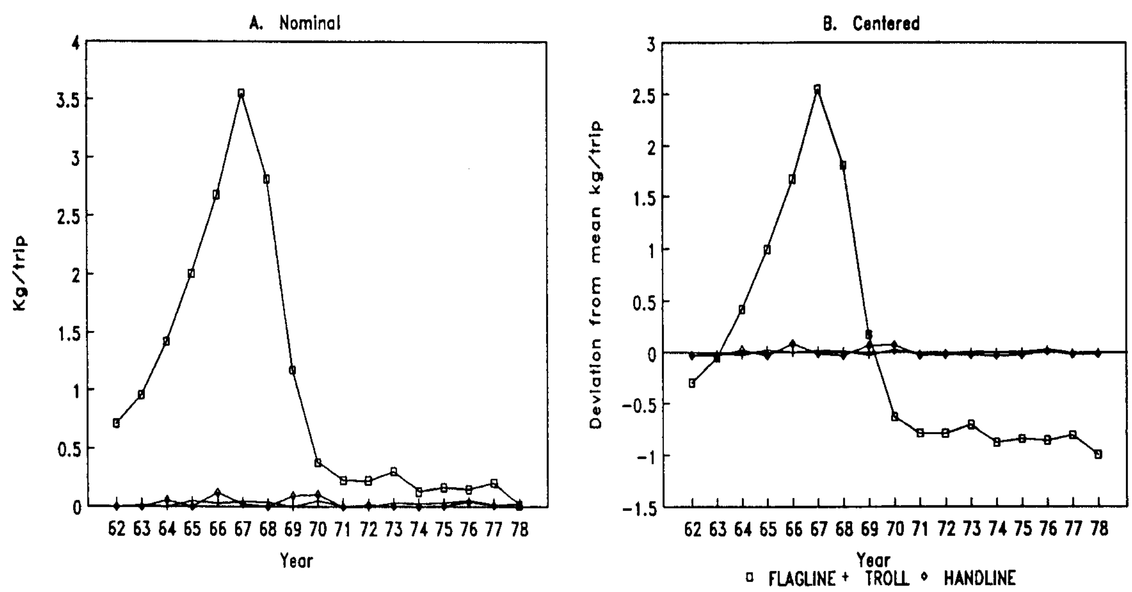


Figure 7.--Annual sailfish catch rates (in kilogram per presumed trip) for domestic flagline, troll, and handline.

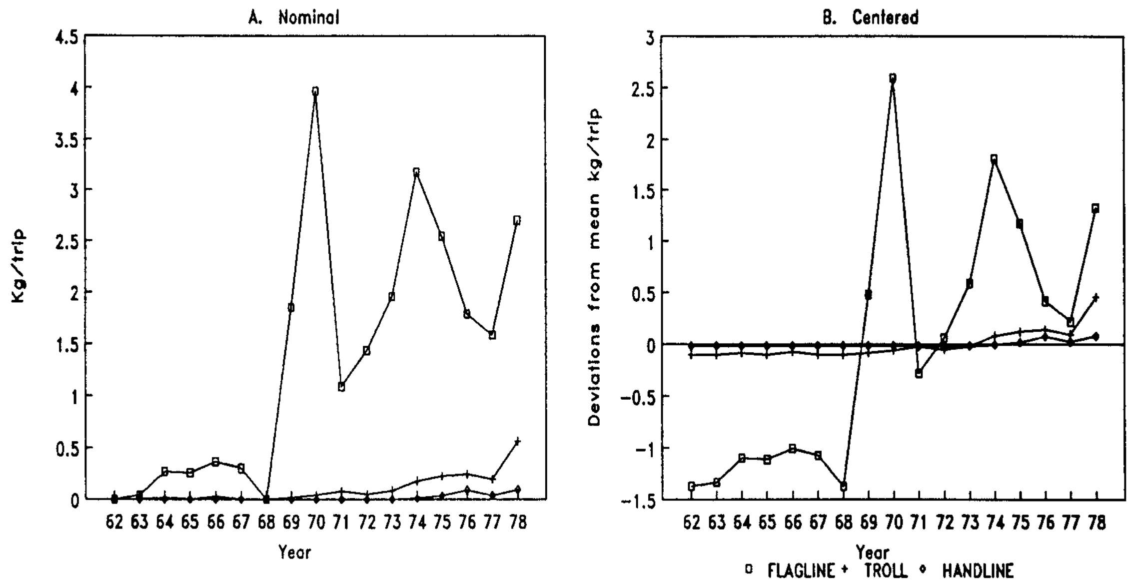


Figure 8.--Annual shortbill spearfish catch rates (in kilogram per presumed trip) for domestic flagline, troll, and handline.

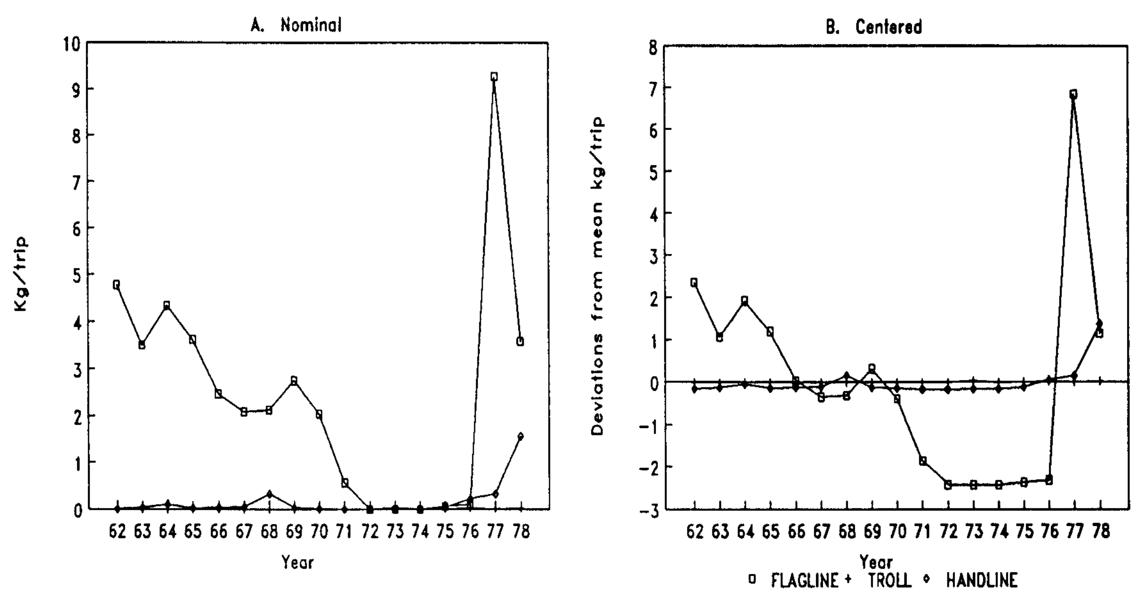


Figure 9.--Annual swordfish catch rates (in kilogram per presumed trip) for domestic flagline, troll, and handline.

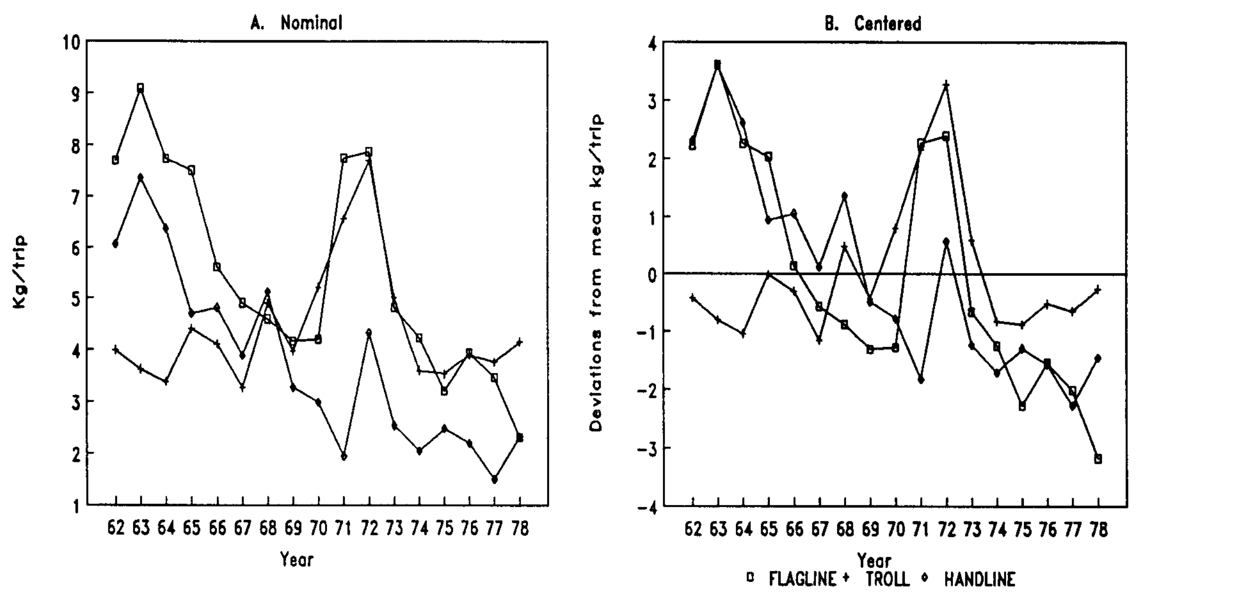


Figure 10.--Annual mahimahi catch rates (in kilogram per presumed trip) for domestic flagline, troll, and handline.

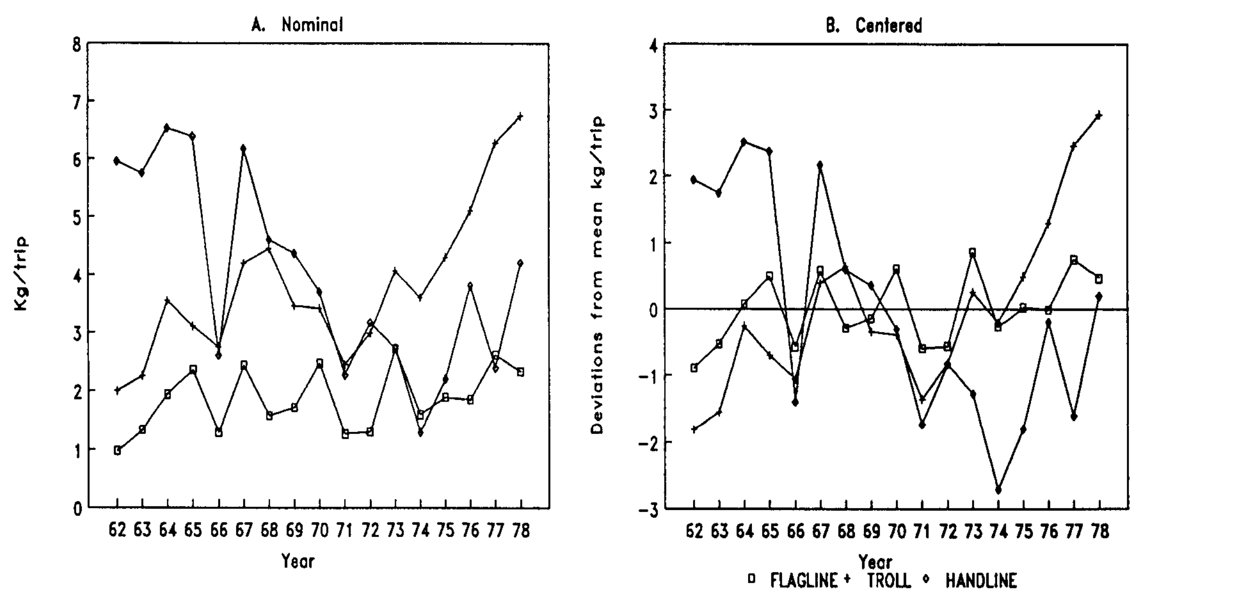


Figure 11.--Annual wahoo catch rates (in kilogram per presumed trip) for domestic flagline, troll, and handline.

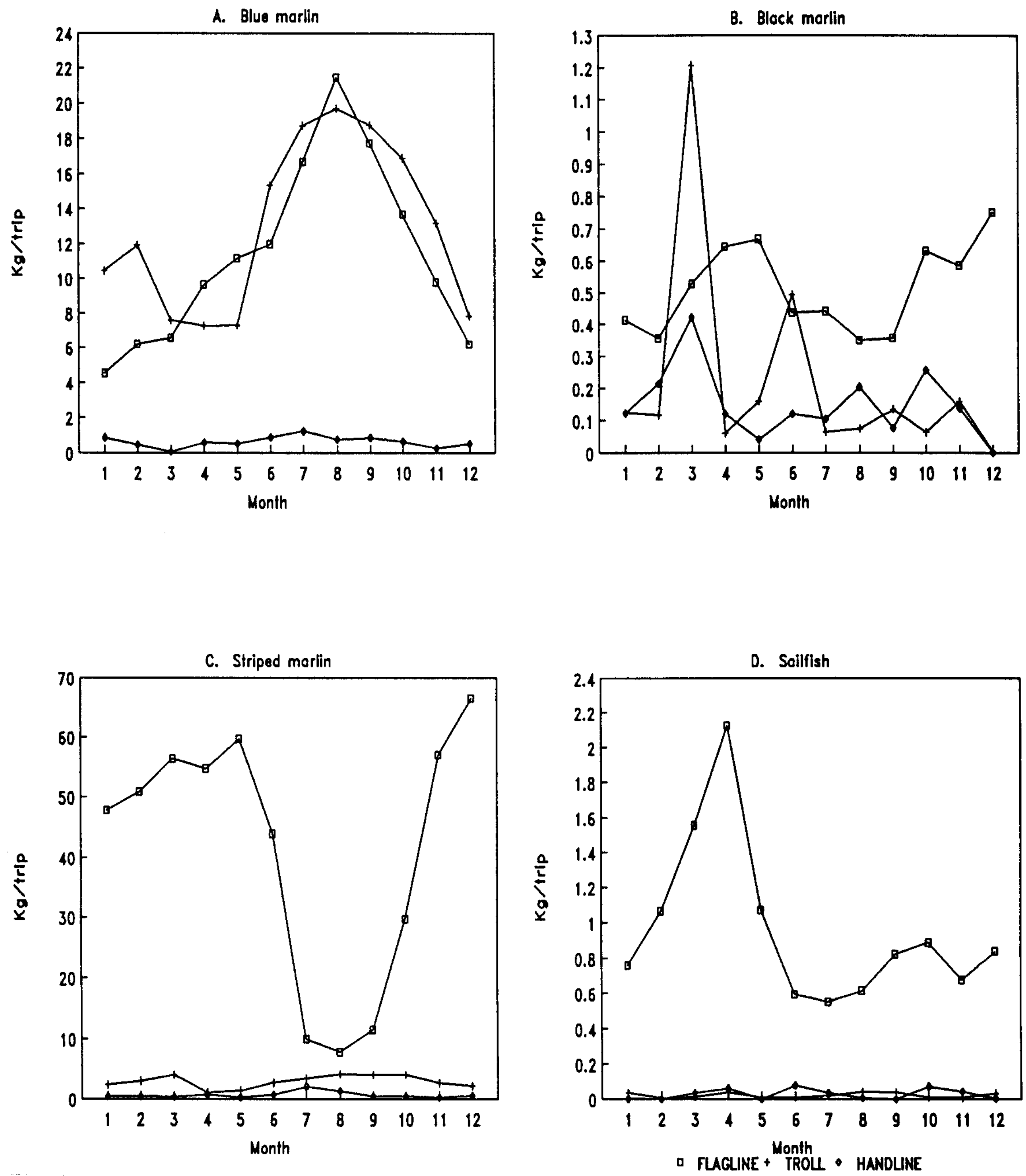


Figure 12.--Monthly catch rates of (A) blue marlin, (B) black marlin, (C) striped marlin, (D) sailfish, (E) shortbill spearfish, (F) swordfish, (G) mahimahi, and (H) wahoo (in kilogram per presumed trip) averaged over 17 years for domestic flagline, troll, and handline.

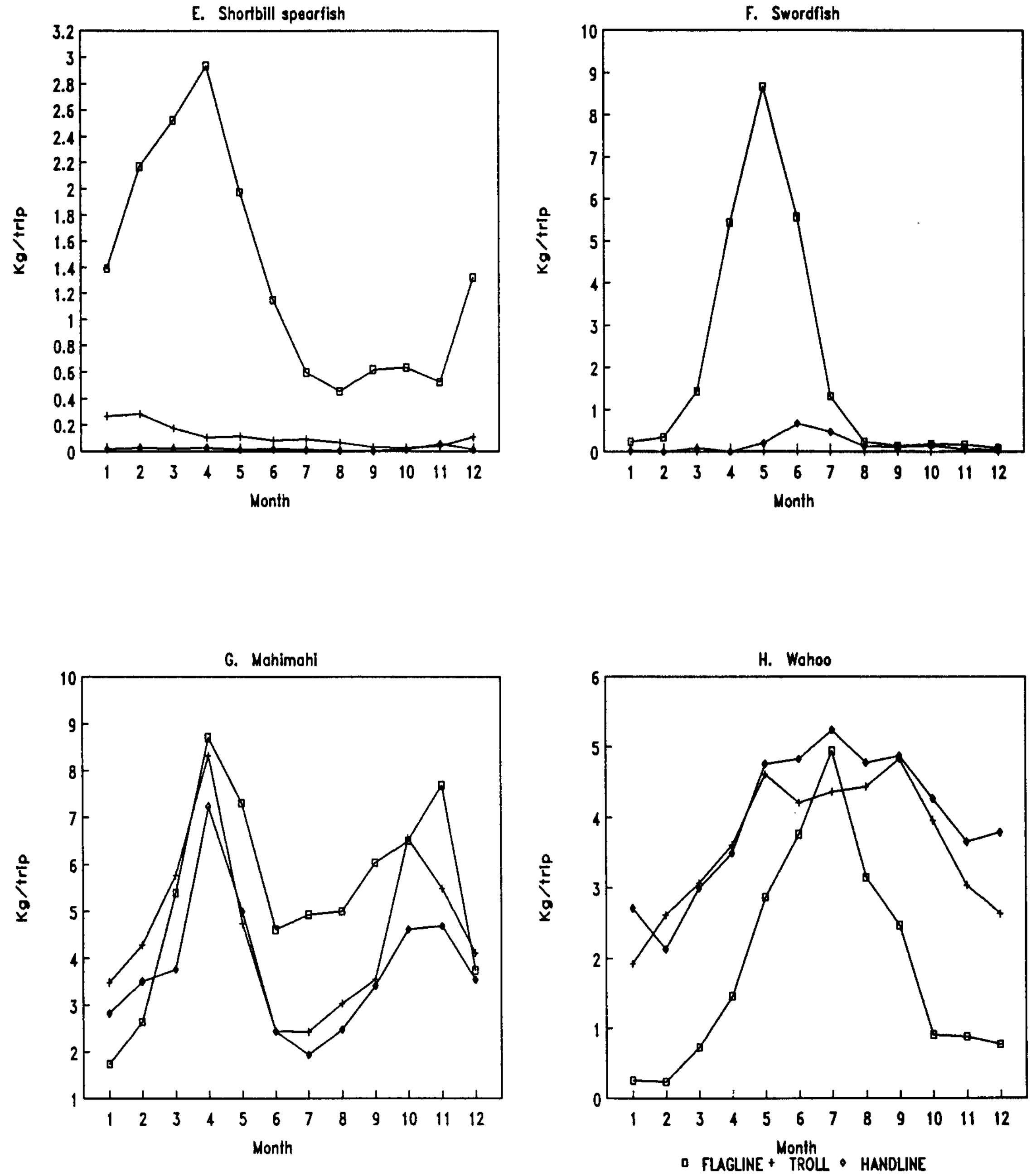
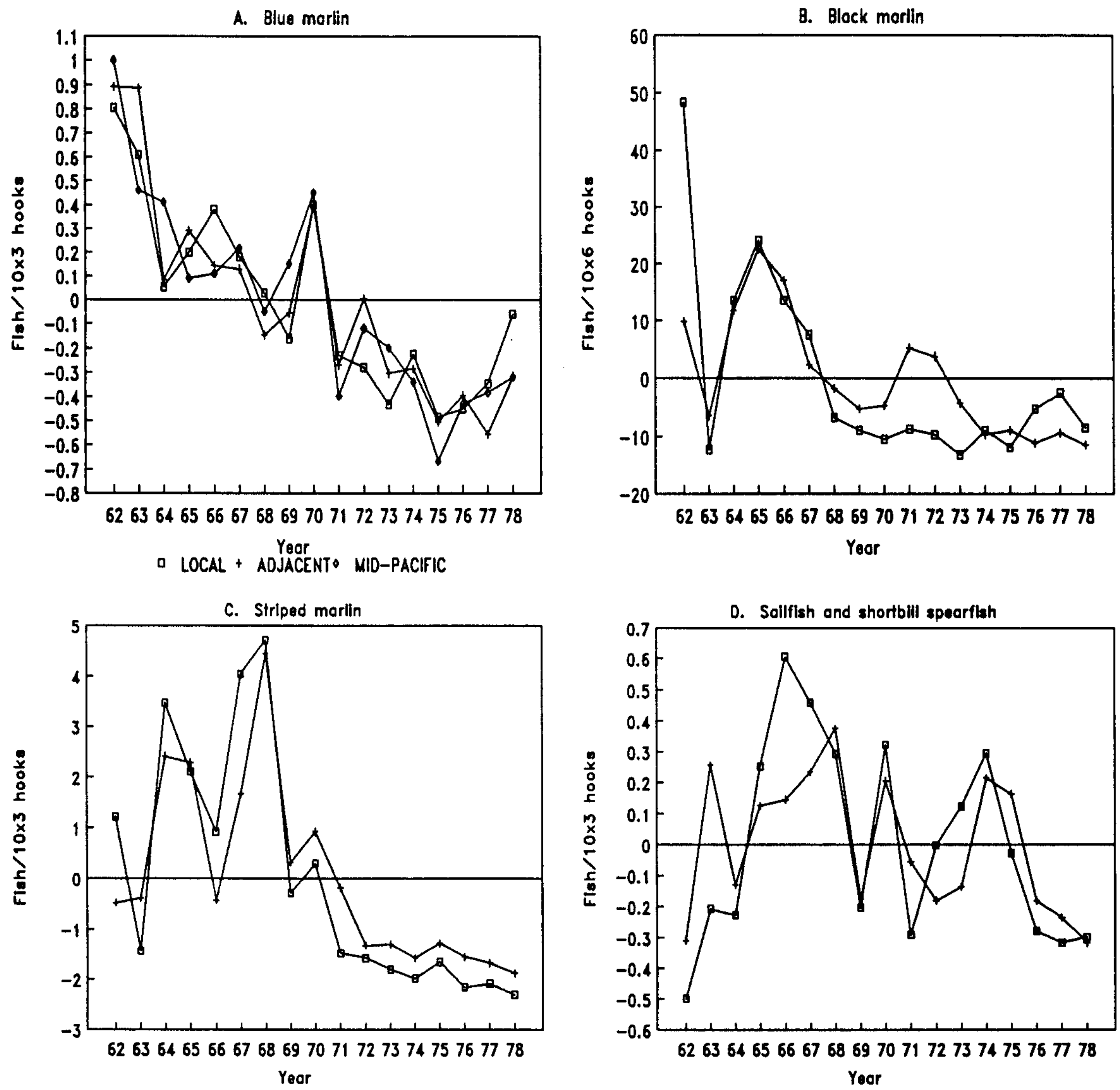


Figure 12.--Continued.



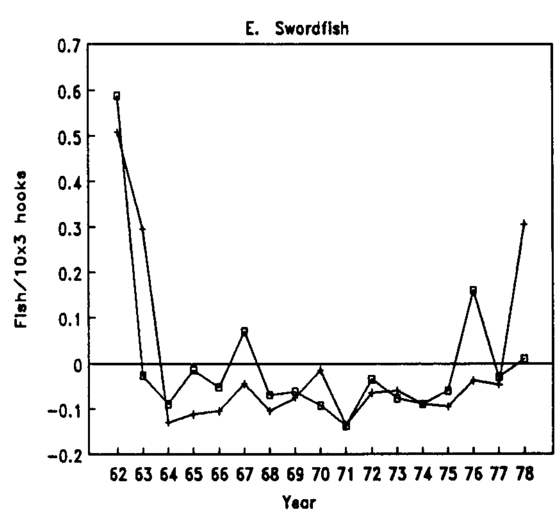


Figure 13.--Centered annual catch rate in fish per thousand or million hooks for Japanese tuna longline in local, adjacent, and mid-Pacific areas of (A) blue marlin, (B) black marlin, (C) striped marlin, (D) sailfish and shortbill spearfish, and (E) swordfish.

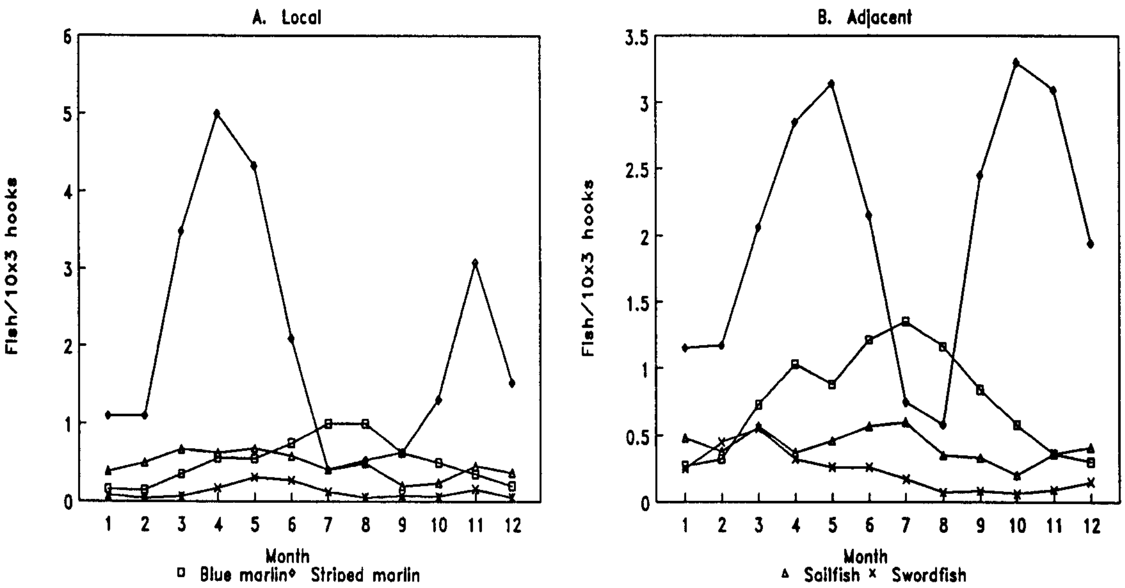


Figure 14.--Monthly catch rates of blue marlin, striped marlin, sailfish (including shortbill spearfish), and swordfish (in fish per thousand hooks) for Japanese tuna longline in (A) local and (B) adjacent areas.